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The early to mid-Holocene moist period in Arabia: some recent evidence from lacustrine sequences in eastern and south-western Arabia

ADRIAN PARKER, CAROLINE DAVIES & TONY WILKINSON

Abstract
During the early and mid-Holocene much of the Arabian peninsula was significantly moister than it is today. In recent years several new sedimentary sequences from relict lake beds have strengthened the original observations and demonstrate that there was significant variation in this wet period, both in time and space, due to variations in local geography as well as global patterns of circulation. This paper builds upon recent fieldwork and analyses conducted by the authors in the Awāfi area of Ras al-Khaimah, UAE, and the Dhamār area in Yemen. The 3.3 m lake sequence from Awāfi demonstrates the existence of lakes from 8500 BP until around 4100 BP, whereas several relict lakes in the Yemen highlands show that moist conditions were in place from 10,000 BP until at least 6800 BP, and perhaps as late as 3850 BP. Such a moist interval is relevant to the patterns of exploitation of Neolithic communities and the paper will make some preliminary suggestions as to how this might have influenced patterns of settlement and land use.

Keywords: lakes; climate change; Arabian Neolithic; prehistory

Introduction

It is a cliché that Arabia is a land of deserts, even though large areas of south-west Arabia currently have rainfall in excess of 300 mm per annum, a figure that is sufficient for rain-fed agriculture. Moreover, perennial pools of water existed probably throughout the Holocene in areas such as the al-Ḥasā᾿ oasis, at Qatif, and at a number of karstic pools at Aflāj and Jabrin in Saudi Arabia (Neil Munro, personal communication, August 2005). In addition to this geographical variation in moisture, it has been known for several decades that Arabia experienced a moister environment between approximately 6000 and 10,000 years ago (McClure 1976; Roberts 1982; Sanlaville 1992; Roberts & Wright 1993). However, for archaeologists, this episode of moister conditions has been rather ill-defined, so that even as recently as 1990, Dan Potts in his major work on the Arabian Gulf in Antiquity, could report:

> "Unfortunately for the archaeologist, there is no unanimity amongst specialists regarding the absolute chronology of wet, humid phases and dry, arid intervals during the Early and Middle Holocene in the Arabian Gulf." (Potts 1990: 35).

Here we provide a summary of recent data on this moist interval, focusing on two sets of data, the first from eastern Arabia in the United Arab Emirates, and the second from the highlands of Yemen.[1] The evidence is primarily derived from ancient lake deposits, with some support information coming from relict soils (palaeosols). These records are then compared with a recent climate proxy record derived from stalactites (or speleothems) from Qunf Cave located in Dhofar in southern Oman (Fleitmann 2003).

The evidence from relict lakes

Relict lakes are remarkably widely distributed in the Arabian Peninsula, with the following being fairly well known (from north to south on Fig. 1):

— The Nafūd in northern Saudi Arabia (Garrard, Harvey & Switsur 1981).
— Awāfi in Ras al-Khaimah (UAE) (Parker *et al.* 2004).
— Mundafan area of southern Saudi Arabia (McClure 1976; 1978).
— The al-Hawa area, Yemen (Lézine *et al.* 1998).
— The Wahiba Sands, Oman (Gardner 1988; Radies *et al.* 2005).
— The Dhamār region, Yemen (Wilkinson 2005).

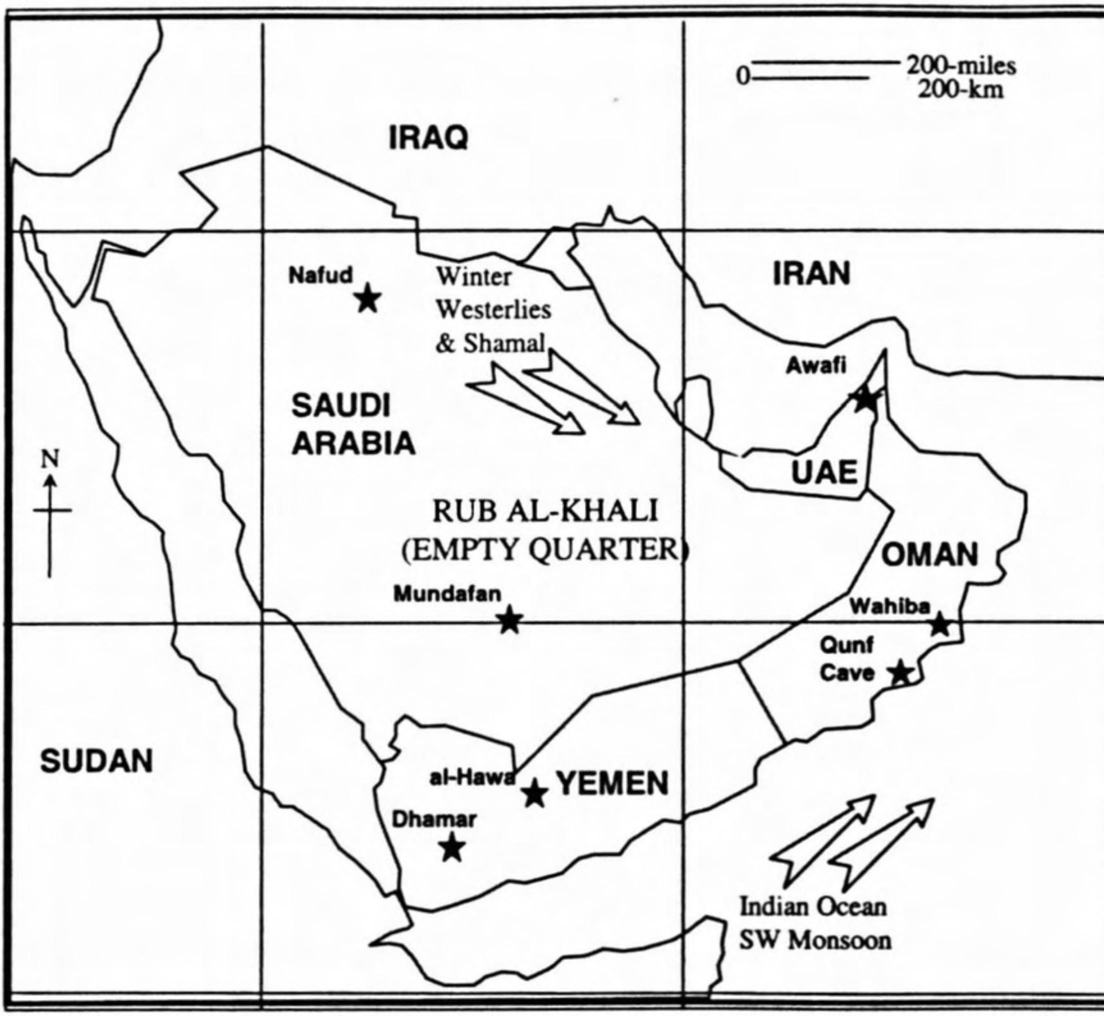

FIGURE 1. *The location of relict Holocene lakes discussed in the text.*

The record of Arabian lakes is mainly restricted to lacustrine deposits, which often consist of white calcium carbonate-rich accumulations, or finely stratified silts and clays. From their contained microfossils and geochemistry these sediments can be identified as having accumulated in bodies of standing water of varied duration (although the hydrological mechanisms behind the formation of such lakes continues to be a matter for debate). These lakes are frequently the locus of considerable Neolithic activity as noted by Zeuner (1954), Field (1958; 1960), McClure (1976), Edens (1988), and Masry (1997).

Palaeosols

In the context of the present article palaeosols are buried soils that have developed within a stratigraphic succession and which show a clear signature of their formation in the form of relict soil horizons. In the case of Arabia, such soils represent phases of stability of sufficient duration to leave distinctive soil "A" horizons that are frequently enriched in humus so that they remain as dark buried horizons.

Although a number of relict soils are known from parts of Saudi Arabia such as the Wadi Danah basin (Anton 1984: 286–287), probably the most distinctive are known from Yemen, namely from the Wadi Jubah basin (Brinkmann 1996: 202–211; Overstreet & Grolier 1996: 363–374), the Wadi al-Thayyilah (Fedele 1990), and the Dhamār region (Wilkinson 1997; French 2003). The humus-rich palaeosols of southwest Arabia provide some indication of past climate, and their presence implies that environmental conditions were moister during their formation. However, they should primarily be regarded as indicators of earlier land surfaces that were stable for sufficient time for humic soil horizons to develop. Although a compelling case can be made for their development during moister environmental conditions, their chronological relationship to the history of the Holocene moist intervals makes them a more ambiguous indicator than lakes.

The Awāfi sequence

Of the two sequences to be discussed, the Awāfi sequence is sufficiently far north to have been only partly under the influence of the Indian Ocean Monsoon during the Holocene. The relict lake deposits at Awāfi, Ras al-Khaimah, United Arab Emirates (UAE) (25° 42' 57"N, 57° 55'57"E) accumulated within a closed lake basin extending over some 2 km^2 (see Parker *et al.* 2004: fig. 2). The basin is bounded by 50 m-high megalinear dunes of Late Glacial Maximum, Younger Dryas and earliest Holocene age (Goudie *et al.* 2000). An early to mid-Holocene phase of lacustrine sedimentation was then followed by a later phase of aeolian activity that prevailed over the past 4000–5000 years (Parker *et al.* 2004). Lacustrine sediments were first exposed in section in 1997 as a result of the quarrying of marl for the nearby construction industry. The site was visited in March 2000 and sampled for palaeoenvironmental investigation. The site has been examined for pollen, phytoliths and selected physical and geochemical sediment properties (Parker *et al.* 2004). Owing to the excellent record found at Awāfi the site was visited and resampled in January 2005. Contiguous 1 cm sampling was undertaken in order to provide a high-resolution (decadal-centennial) record. This latter part of the study is ongoing as part of a PhD project.

Four main sedimentary units (Fig. 2) were identified in the field:

— A basal gravel lag deposit overlain by yellow/orange mottled sand (Unit 1) is dated to the Last Glacial Maximum (Optically Stimulated Luminescence (OSL)) date of 17,650 ± 1790 BP.

— Unit 2, an early Holocene carbonate-rich marl with laminations, was deposited within the lake. Pollen and phytolith analysis shows that the surrounding

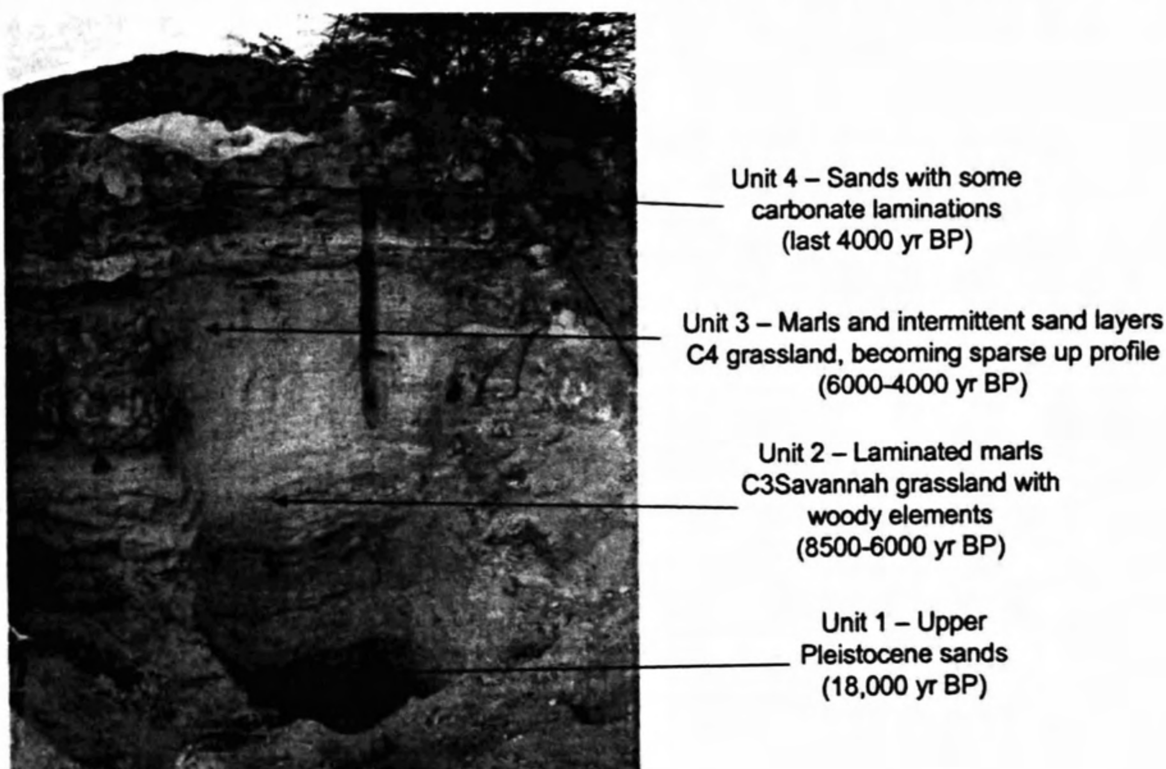

FIGURE 2. *The lake sequence at Awāfi, UAE showing the 3.5 m-deep stratigraphic succession.*

vegetation consisted of C3 (2) savannah grassland with woody elements (8500–5900 Cal. yr. BP; *c.* 6500–3900 Cal. yr. BC).
— This was followed during the mid-Holocene by the accumulation of marls and sands of unit 3. Surrounding vegetation included C4 grassland, becoming sparse up profile (5900–4500 Cal. yr. BP; *c.* 3900–2500 Cal. yr. BC).
— Finally, the last 4500 years of the late Holocene witnessed the accumulation of the upper Unit 4, which primarily consists of aeolian red sands with fine carbonate laminae. These indicate a dry lake basin with periodic inundation and frequent episodes of windblown sand (i.e. *c.* 2500 Cal. yr. BC to present).

A total of eight dates (six AMS C^{14} and two OSL) constrain the age of the deposit. The lake formed at *c.* 8500 Cal yr. BP (i.e. 6500 Cal. yr. BC) probably owing to the northwards incursion of the Indian Ocean Monsoon to this latitude (i.e. 25° 42' 57" N). At the same time during the early Holocene the dune field became stabilized and vegetated with C3 grasslands and scatters of woody elements including *Acacia*, *Prosopis*, and *Tamarix*. The accumulation of Unit 3 coincided with the onset of regional aridity, aeolian flux and dune reactivation and accretion, and at this time it appears that the Indian Ocean Monsoon weakened and retreated southwards around 6000 Cal. yr. BP (*c.* 4000 Cal. yr. BC). Despite this reduction in precipitation the lake was maintained by winter-dominated rainfall and there was a shift to drier adapted C4 grasslands across the dune field.

West of the Oman Peninsula within the United Arab Emirates large-scale occupation corresponding to the Neolithic (of Arabian Bifacial Tradition and ʿUbaid-related cultures) is suggested to have terminated around 5900 Cal. yr. BP (*c.* 4000 Cal. yr. BC; Uerpmann 2003), with the result that there is no further archaeological evidence for almost a millennium. Uerpmann (2003) infers, however, that there was no equivalent gap in settlement to the east of the Hajar mountains of Oman, where settlement continued throughout the fourth millennium BC. A minor reversal to moist conditions occurred between 5000 and 4200 Cal. yr. BP and an increase in lake level coincided with the reoccupation of the landscape during the Hafit and Umm an-Nar periods. During this period there was significant reoccupation of oasis settlements in the region, which continued until around the end of the third millennium BC. It should be emphasized, however, that this occupation occurred within a period that was, in general, drier than most of the preceding Neolithic. Desiccation of the Awāfi lake basin at 4200 Cal. yr. BP then ushered in a long period of arid climatic conditions, which have continued until the present day. This aridification coincides approximately with the early part of the Wadi Suq phase during which much of the inland belt of oases was abandoned (Carter 1997).

Lakes in the Yemen Highlands around Dhamār

Relict lakes have been known in the Yemen highlands since the soil surveys of the 1970s recognized lacustrine deposits and extensive scatters of shells of freshwater molluscs in the plains of the Qāʿ Jahrān (Acres 1982). Unlike the Awāfi site, these relict lakes occur at very high elevations (*c.* 2400 m above sea level), and within the full effects of the Arabian Ocean monsoon. Since the original studies, the Dhamār survey has recognized several additional lake basins, in addition to the above-mentioned Qāʿ Jahrān. Newly discovered lake sequences were found at Zeble to the east of Dhamār, and al-Adhlaʿ, near the site of Masna ʿat Maryah to the west. Numerous sections have been recorded in well holes, quarry pits, and drainage cuts, and in most exposed sections the characteristic Jahrān palaeosol has been recognized to lie stratigraphically above the lake deposits.

Like their counterparts in the United Arab Emirates, the Dhamār lake deposits consist of accumulations of calcium carbonate-rich lacustrine marls. In the Qāʿ Jahrān to the north of Dhamār, 2–3 m-deep accumulations of fine sediments overlie alluvial sands and (in some locations) gravels deposited during the late Glacial period before *c.* 10,000 years ago.

The Bet Nahmi sequence (from near Ma ʿbar, Qāʿ Jahrān) mainly consists of grey marls deposited in marshes or lakes (Fig. 3). The pale grey lake deposit is around 1 m deep and contains two species of freshwater molluscs. These have yielded radiocarbon determinations in the range 7940 Cal. yr. BP for the base (5990–6160 Cal. yr. BC), and 7310–7430 Cal. yr. BP (5360–5480 Cal. yr. BC) for the upper part of the deposit. Two thin palaeosol horizons Ab2 and Ab3 representing phases of land surface stability (as well as relatively drier conditions) are found below this lake deposit, but are undated. On the other hand the deep lacustrine marl is overlain by an erosional discontinuity followed by an additional marl horizon (Bk1) containing freshwater shells dated in the range 3690–3900 Cal. yr. BP (1740–1950 Cal. yr. BC).

Similar lake marls were recorded at al-Adhlaʿ (Wilkinson 2003), and at Zeble, to the east of Dhamār where a poorly defined elongate lake basin contains a

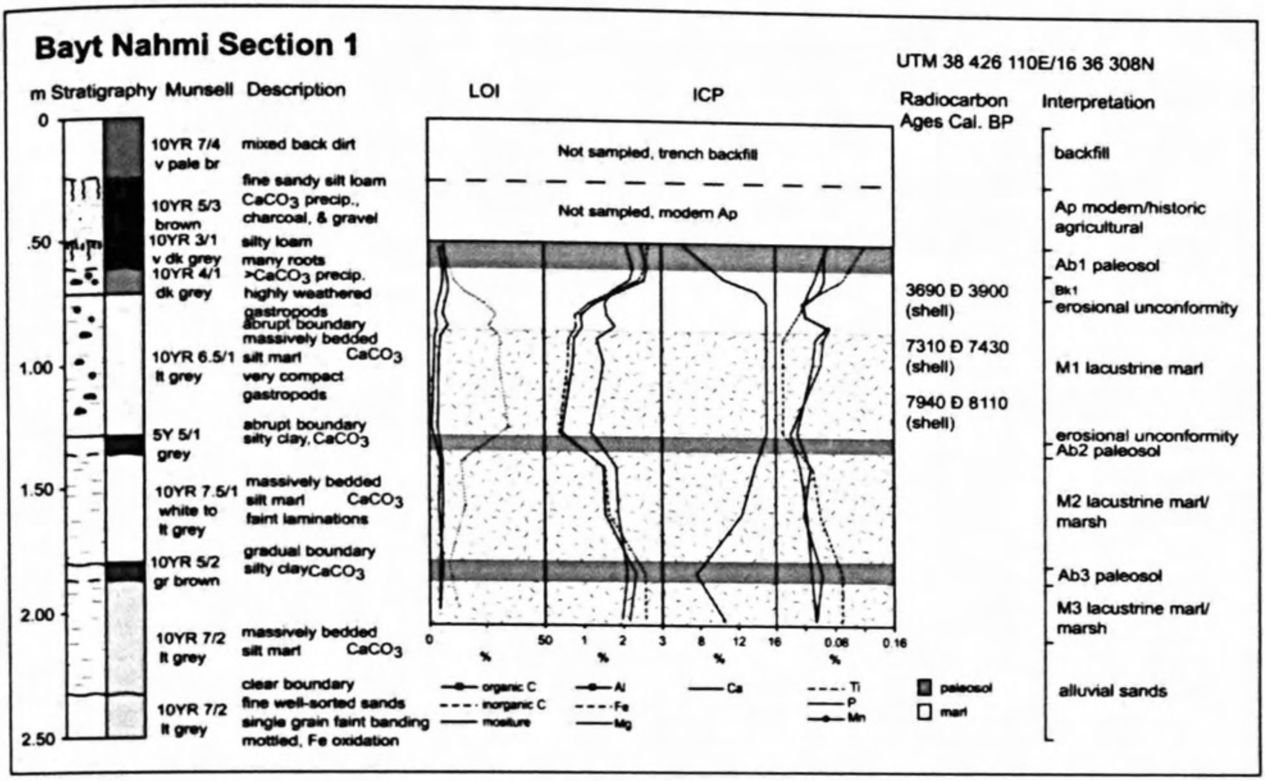

FIGURE 3. *The sequence of lake sediments at Bet Nahmi in the Qāʿ Jahrān north of Dhamār.*

complex 2 m-deep sequence of laminated marls and palaeosols. The Zeble sequence consists of (at the top) a thin calcreted horizon below which occurs a white silt marl, part of which may relate to a period of marsh accumulation. Sediments between 40 and 60 cm in depth contain obsidian artefacts, probably belonging to a nearby prehistoric occupation. Below this a thin palaeosol (Ab1) represents a brief phase of drying and some land surface stability, and a second palaeosol (Ab2) is underlain by additional marl sediments of shallow lakes or marshes. Dates from the palaeosols Ab1 and Ab2 provide radiocarbon determinations in the range 7940–8030 Cal. yr. BP (6080–5990 Cal. yr. BC) and 9900–10,200 Cal yr. BP (8250–7950 Cal. yr. BC), whereas the determination on freshwater shells from the overlying calcrete is older than the determination from the organic matter in the palaeosol immediately beneath. This calcrete date (8690–8930 Cal. yr. BP; 6980–6740 Cal. yr. BC) may be anomalously old due to a reservoir carbon effect in the calcrete. Below a depth of approximately 90 cm, a deep sequence of banded lake marls, although undated, may represent an earlier phase of Pleistocene lake development.

The extent of the lake at Zeble is unknown, but it may possibly link with a shallow sequence of lake or marsh sediments recorded by the Dhamār survey at Mahnashah near Sedd adh-Dhraʾ (Wilkinson 1997: 845–847). The Zeble relict lakes and marshes are overlooked by prominent high cliffs upon which was found one of the few Neolithic sites in the region to yield significant numbers of bifacial foliate points (site DS 281). This small assemblage mainly consisted of foliate arrowheads of chert and obsidian, which may have formed the toolkit of the members of a small hunting camp overlooking the mid-Holocene lake. Large numbers of obsidian flakes and other lithics are found in the area surrounding the lake deposits (and indeed in some of the uppermost deposits), but none of these can be readily dated typologically to the Neolithic. Nevertheless, the absence of pottery of Bronze and Iron Age date suggests that much of this lithic scatter may belong to a Neolithic occupation, but the construction of terraced and other fields in the Zeble lowlands has disturbed any possible site. It is therefore not clear whether a lower settlement on the plains at one time acted as a complement to a hunting camp on the nearby cliffs.

If a single radiocarbon determination from the lake deposits at al-Adhlaʿ (12,100–11,280 Cal. yr. BP) is added to the other evidence for Yemeni lakes, the moist period of the Yemen highlands can be seen to fall in the range 12,100–7400 Cal. yr. BP (*c.* 10,000–5400 Cal. yr. BC). This corresponds approximately to the period of high lake levels in the Arabian interior, although the Bet Nahmi post-palaeosol lacustrine phase of 3690–3900 Cal. yr. BP appears to coincide with a similar late lake at Awāfi (Parker *et al.* 2004: 674). It is therefore possible that occupation of the nearby Bronze Age settlement at Hawagir (DS 293) might have coincided with a brief phase of lake development during the second millennium BC.

Arabian lakes in the context of the regional environmental and archaeological records

In recent years the Holocene record of the Indian Ocean Monsoon has become well known thanks to the proliferation of cores sunk into the bed of the Indian Ocean. These records demonstrate that the monsoon and ocean upwelling associated with it was at its maximum from at least 10,000 to 6000 Cal. yr. BP (i.e. 8000–4000 Cal. yr. BC), and that the Holocene climate settled down to something resembling the present regime, albeit with minor fluctuations, at around 4000 Cal. yr. BP (2000 Cal. yr BC; Sirocko 1996; Zonneveld *et al.* 1997). In addition to these oceanic cores, land-based records are starting to bear fruit, and here we compare the records of radiocarbon dated Neolithic occupations and the records of Yemeni lakes with a high-resolution speleothem record obtained from Qunf Cave in Dhofar, Southern Oman (Fleitmann *et al.* 2003). A similar record, recently published from Hoti Cave in the mountains of northern Oman (Burns *et al.* 2001), shows periods of rapid growth during the peak phases of interglacials, specifically during the period between 6000 and 10,000 Cal. yr. BP, but this record is shorter and of lower resolution than that from Qunf Cave. The sequence from Qunf Cave, located at an elevation of *c.* 650 m above mean sea level, is for an area in which 90 % of the annual precipitation falls within the summer months as monsoonal rainfall. The range of this record, from *c.* 10, 300 to 400 Cal. yr. BP (but with a hiatus between 2700 to 1400 Cal. yr. BP), accords with the main phases of human occupation in Arabia. Here a smoothed record from Qunf Cave (in which the fine-grained fluctuations have been averaged out by the calculation of running means) is compared with the radiometric dates of Neolithic activity from the United Arab Emirates, as well as the chronology of lakes and palaeosols in Yemen and the Rubʾ al-Khālī (Figs 4–6). Radiocarbon estimates do not indicate the dates themselves, but rather employ summations of the distributions of their probabilities, a technique which estimates more realistically the record of measured activity as it is currently known from the region. We emphasize, however, that these radiocarbon records are only as good as the amount of data available to the authors. Future work in the region could considerably extend or change these records.

When the chronology of lake sediments from the Rubʾ al-Khālī and highland Yemen is compared with the Qunf Cave proxy climate record, there is a broad relationship between the moist period at Qunf, as indicated by the oxygen isotope record, and the summed radiocarbon record from the lakes (Fig. 4a and b). The gaps in the highland lake record are probably an artefact of the small number of processed radiocarbon determinations, but it does appear that the Yemeni lakes first develop just before the moist interval at Qunf, whereas the final significant burst around 6000 Cal. yr. BP (*c.* 4000 Cal. yr. BC) corresponds approximately to that period at Qunf when the climate was drying significantly. Equivalent dates for lakes in and around the Rubʾal-Khālī show a closer correspondence to the Qunf record (Fig. 4a) as well as some correspondence in points of detail. Specifically, both records register a weakening of the monsoon around 8200–8400 Cal. yr. BP (6200–6400 Cal. yr. BC) which corresponds to the so-called 8200 BP event, a period when there was significant cooling and drying of part of the earth's climate system (Alley *et al.* 1997).

The Yemen palaeosols, on the other hand, date to a period significantly after the lakes and tend to cluster after the 8200 BP event, that is during the later part of the moist period (Fig. 4c). This confirms the stratigraphic relationship already noted, in which the palaeosols tend to overlie the lake sediments (although in some cases, as at Bet al-Nahmi, palaeosols develop within the lacustrine sequence as well). Under certain circumstances the humic palaeosols relate to moister conditions, but as palaeosols they also represent phases of stability of the terrain. Therefore when they are associated with lacustrine sequences they correspond to phases when the lakes actually dried out. Nevertheless, that they also relate to moister conditions is also evident from the existence, at Sedd adh-Dhraʾ, of a peat deposit (sadly lacking preserved pollen) which must have required significantly wetter conditions to form and be preserved. The date of this peat (9710–10,140 Cal. yr. BP), together with the date from al-Adhlaʿ of 12,100–11,280 Cal yr. BP, confirms the suspicions raised by the Qunf record that the onset of moist conditions occurred

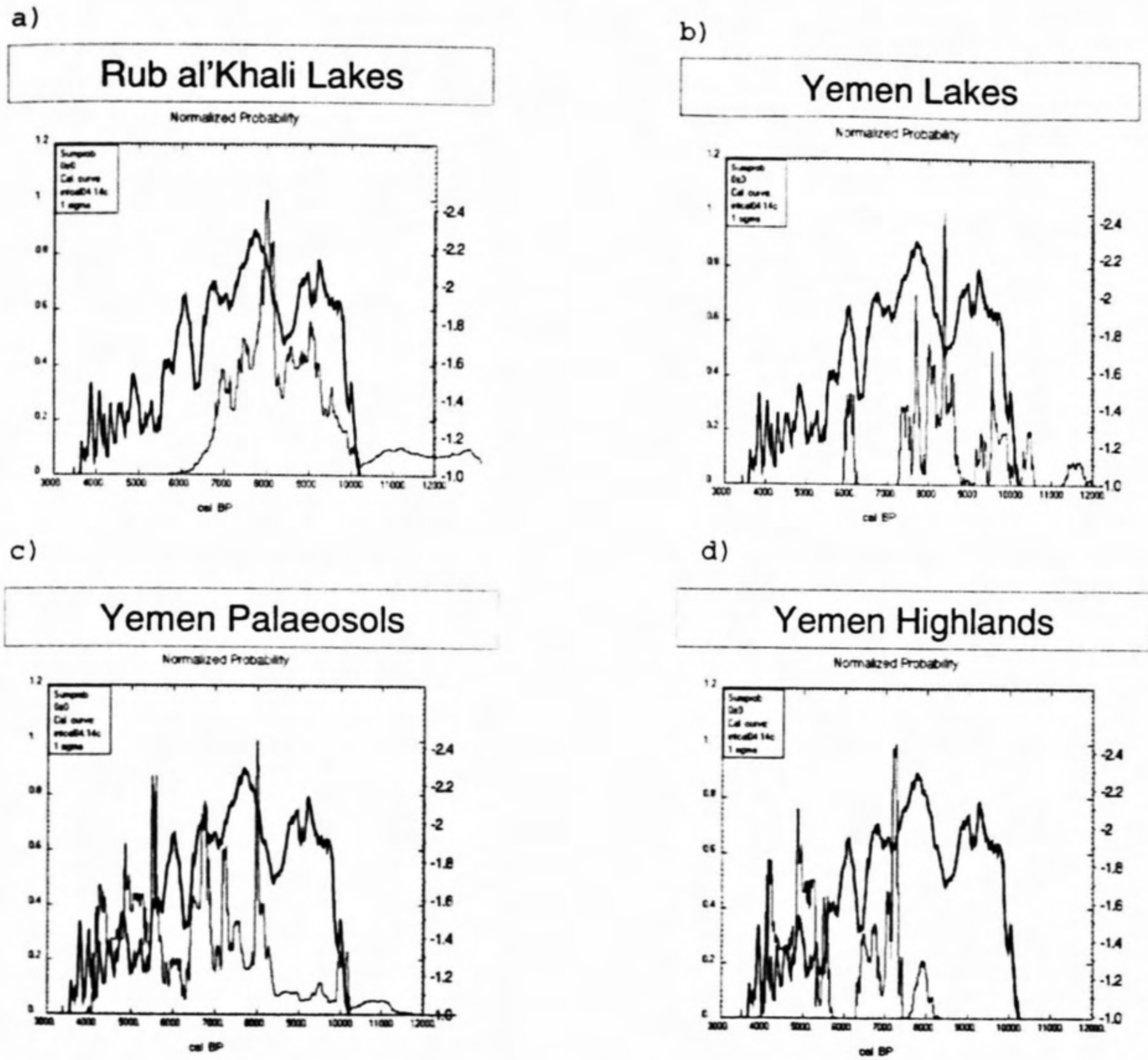

FIGURE 4. *Summed probabilities of radiocarbon assays from:* ***a.*** *Rubᶜ al-Khālī lakes;* ***b.*** *lakes from highland Yemen;* ***c.*** *Yemeni palaeosols;* ***d.*** *dates on Neolithic activity in the Yemen highlands* compared with the smoothed climate proxy curve (derived from oxygen isotope analysis of stalactites from Qunf cave in Fleitmann* et al. *2003). Note: the scale on the horizontal axes is in years before the present (calibrated BP); dates from* ***d.*** *marked * are mainly derived from artefacts within the palaeosol, hence they tend to overlap with those of category* ***c.***

rapidly between 10,000 and 12,000 Cal. yr. BP (Fig. 4b).

When the record of Neolithic activity within the desert interior of the United Arab Emirates (which includes sites such as Jebel al-Buhais: Uerpmann, Uerpmann & Jasim 2000), is compared to the proxy record from Qunf Cave, there is a broad correspondence between Neolithic activity in the desert areas and the moist interval (Fig. 5a). Nevertheless, there is a slight time lag with the Neolithic activity starting some time after the environment became moist. There are also interesting correspondences in points of detail so that high levels of dated Neolithic activity correspond to moist episodes at *c.* 7700, 6600, and 6000 Cal. yr. BP (i.e. 5700, 4600, 4000 Cal. yr. BC). On the other hand, if radiocarbon-dated Neolithic activity on the coast of the United Arab Emirates is compared with the Qunf record, the record differs from that of the interior deserts (Fig. 5b). Although there is again a broad correspondence between the moist interval and dated activity (often in the form of Neolithic shell middens), there are both correspondences and anti-correlations between the two records. Not only are there high levels of activity at 6600 Cal. yr. BP and 6000 Cal. yr. BP, but equally, certain wetter phases witness a dearth of radiocarbon-dated activity on the coast, for example between 7500 and 7700 Cal. yr. BP and at about 4800 Cal. yr. BP (5500–5700 and 2800 Cal. yr. BC). Although one should not make too much of these finer grained anti-correlations, they might fruitfully be looked at in the context of the natural cycle of human movements in the regions (Phillips 2002: 182).

Neolithic communities of Arabia were once regarded primarily as hunter-gatherers (Tosi 1986), but the analysis of faunal remains from sites such as Jebel Buḥaiṣ indicates that the inhabitants practised a significant degree of mobile pastoralism (Uerpmann, Uerpmann & Jasim 2000). In the context of Jebel Buḥaiṣ, it has been suggested that Neolithic communities may have been resident on coastal shell middens during the winter, and then moved to inland sites such as Buḥaiṣ in the spring and ultimately to the cooler climate of the mountains during the summer (Uerpmann *et al.*, in press). In other cases, communities may have taken advantage of forage nourished by winter rainfall in the desert interior and then spent much of the remainder of the year at the coast or in the mountains. In the context of the changing climate, during moister periods there may have been less emphasis on coastal resources as mobile communities took advantage of the availability of forage in the deserts. At such times communities may have resided in the desert all year because a strengthened monsoon would have resulted in increased summer rainfall, thereby increasing the availability of forage for year-round grazing. This might account for the lack of occupation at coastal locations during moister intervals, although processes of site preservation and discovery may partly account for such gaps. On the other hand, dry conditions could witness pastoral communities focusing upon coastal settlement or at favoured wet point sites for longer periods of time.

Bearing in mind complications arising from the differential preservation and discovery of prehistoric sites, which should not be underestimated, we can make the following generalizations about relationships between climate and settlement in southern and eastern Arabia. First, there is a general relationship between moist phases and Neolithic settlement. If we place the recognized cultural phases within the pattern of climate change it is evident that sites of the Fasad tradition as conventionally defined (Edens 1988; Cleuziou & Tosi 1998; Zarins 1998; Potts 1990: 32–54) follow with a significant time lag the initial stages of the moist interval and the period when lakes were developing for the first time (Fig. 6). Similarly, sites associated with artefacts of the Arabian Bifacial Tradition and ʿUbaid pottery fall within the later part of the wet phase (between 5800 and 7300 Cal. yr. BP, i.e. 3800 and 5300 Cal. yr BC) when the interior, although moister than today, would have been somewhat drier than it was during the

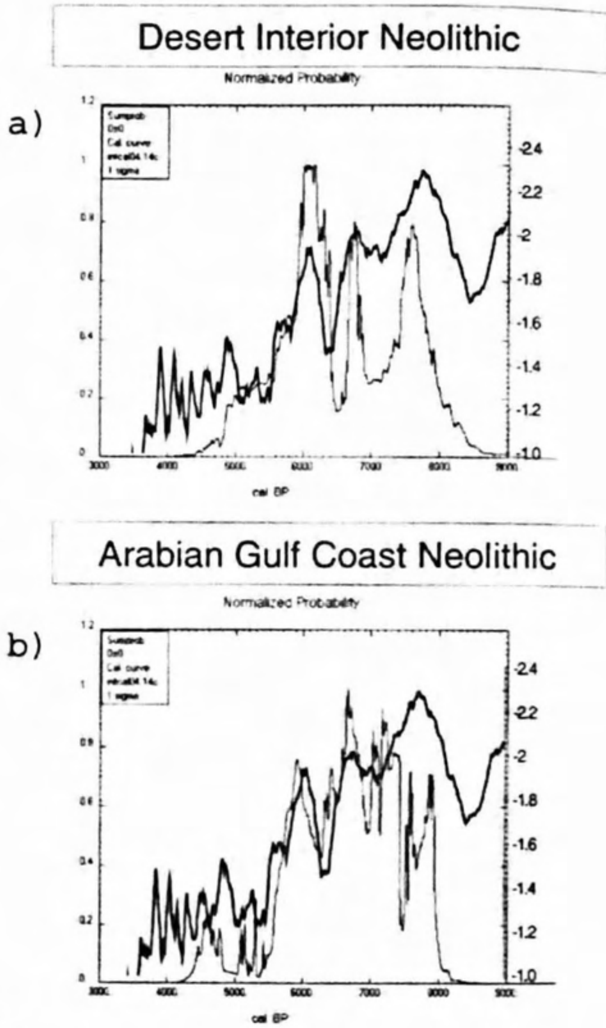

FIGURE 5. *Summed probabilities of radiocarbon assays from:* ***a.*** *sites in the desert interior of the UAE;* ***b.*** *middens along the UAE coast, compared with the smoothed climate proxy curve (derived from oxygen isotope analysis in Fleitmann* et al. *2003). Note: the scale on the horizontal axes is in years before the present (calibrated BP).*

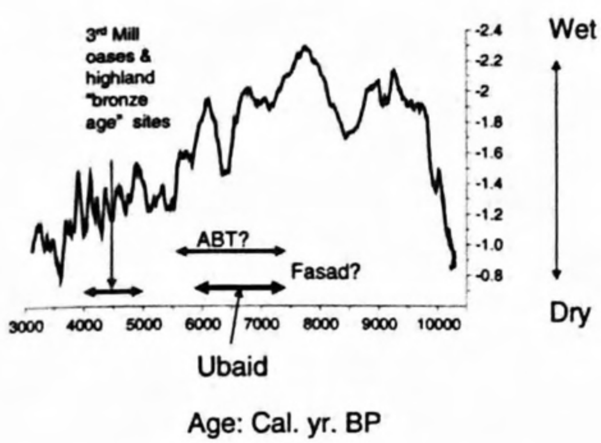

FIGURE 6. *The climate proxy curve from Qunf Cave, Oman (Fleitmann* et al. *2003) compared with traditional assessments of the main cultural phases of the interior of Arabia.*

peak of the Arabian moist phase. Even if we allow for an extended time range for the use of the lithics of the Arabian Bifacial Tradition,[3] there is still a time lag between significant Neolithic occupation and the existence of moist conditions. This suggests that either southern Arabia was sparsely populated during the earlier Holocene, or that there remains a significant amount of Neolithic activity to be recognized in the region.

At a finer degree of resolution, in the UAE and adjacent parts of eastern Arabia (as indicated on Fig. 5), episodes of moister climate as exemplified at Qunf Cave frequently corresponded to peaks of occupational activity within the desert interior. On the other hand, there were also instances when there was less activity on the coasts during moist phases as a result, arguably, of mobile communities spending more of their transhumance cycle taking advantage of enhanced vegetation in the interior steppe or desert.

It is generally recognized that for much of the early to mid-Holocene moist interval, lands adjacent to the Gulf were well populated by sites affiliated with the Arabian Bifacial and ʿUbaid cultural traditions (Potts 1990). Similar dense, albeit relatively mobile, populations were probably in existence in much of the interior of Arabia (Cleuziou & Tosi 1998: 125; Edens & Wilkinson 1998), and Zarins goes so far as to suggest that there was "a veritable explosion of population" during the period of the Arabian Bifacial Tradition (1998: 187). Nevertheless, despite occasional moist episodes, there was a general decrease of moisture between 6000 and 4000 Cal. yr. BP (i.e. during the fourth and third millennia BC). At this time some forager-herder communities probably experienced major declines (McCorriston *et al.* 2005) whereas sedentary settlement became concentrated in oases (Cleuziou 1996), small farming villages (de Maigret 1990), and small hilltop towns (Edens, Wilkinson & Barratt 2000). Alternatively, populations adopted strategies such as nomadism or mobile pastoralism that were better adapted to arid conditions (Zarins 2000: 42). Sedentary settlements were located primarily within the semi-arid margins of the desert or surrounding highlands in both south-east and south-west Arabia, but precisely how the local populations responded to this phase of generally drier conditions is not clear. The apparent coincidence of sedentary settlement with the drying of interior Arabia raises the question of whether the traditional transhumance patterns of the mobile pastoralists were disrupted during the aridification phase of the fourth millennium BC. With the growth of links with the Levant, the Indus Valley, and Mesopotamia, the new sedentary settlements may then have provided a magnet for these marginalized populations. As a result, the region witnessed the growth of sedentary communities within the semi-arid margins of the desert both despite the fact that and because this was a phase of climatic drying. In other words climatic drying made the long-standing pastoral strategies of the interior less feasible whereas "world system" patterns of interaction contributed to the development of new sedentary ways of life in areas that could support the growth of small towns. Consequently, the growing sedentary communities developed in the face of a drying climate with the result that surrounding natural habitats could have been impacted by both increased human-induced degradation as well as suffering from aridity stresses. Although the technologies available were quite capable of overriding the limitations of climate, equally such growth must have exerted a considerable stress on these environments, which in some locations may even have exacerbated the trend towards desertification (Wilkinson 2005: 186–187).

Finally, and as suggested by Lézine *et al.* (1998), there were geographical and chronological trends in the development of the lakes of Arabia. Lakes in the southern part of the peninsula, especially those of highland Yemen (at 15° North), appear to have started earlier (*c.* 10,000 Cal. yr. BP) and continued to at least 7400 Cal. yr. BP (8000–5400 Cal. yr. BC), although isolated episodes of lake development appear to have occurred as late as the early second millennium BC. Progressing north through the peninsula, a very weak trend is evident with lakes starting somewhat later. For example, as far north as Awāfi and in the Nafud (25° and 27° North) lakes start later at around 8500 Cal. yr. BP and finally dry up around 4500 Cal. yr. BP (6500 to 2500 Cal. yr. BC). This suggests that the Indian Ocean Monsoon may have reached further north at relatively later dates, or alternatively, the later phases of lake development may have been associated with a northerly source of moisture such as the winter westerlies. Clearly if the latter was the case it would have had a significant impact on the seasonal mobility of Neolithic communities.

To conclude, at this stage of research it is now possible to sketch a more subtle history for the development of the early and mid-Holocene moist interval of Arabia. Although this episode can be correlated with various phases of occupation of Neolithic communities, these relationships must be understood within the context of the complex movements of mobile populations, both pastoralists and hunter-gatherers, within the landscape. Such movements result in both direct correlations between Neolithic activity and climate as well as more subtle and inverse correlations, depending upon the nature of the sites under consideration.

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Notes

1. The present article summarizes information presented at the 2005 Seminar for Arabian Studies. It is not intended to be a comprehensive review of the evidence; this is being reserved for a longer article to be published in *Arabian Archaeology and Epigraphy.*
2. C3 and C4 plants differ in terms of the way they build up energy through photosynthesis. C3 plants include many temperate grasses, legumes, and cereals whereas C4 plants include most tropical grasses.
3. As demonstrated, for example, at the site of Manayzah in eastern Yemen where tools of this type were present as early as 7800 Cal. yr. BP or 5,800 Cal. yr. BC (Crassard *et al.* 2006).

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Authors' addresses
Adrian Parker, Department of Geography, Oxford Brookes University, Gipsy Lane Campus, Headington, Oxford OX3 0BP, UK.
e-mail agparker@brookes.ac.uk
Caroline Davies, Department of Geosciences, University of Missouri-Kansas City, Robert H. Flarsheim Hall, 5110 Rockhill Rd, Kansas City, MO 64110, USA.
e-mail daviesc@umkc.edu
Tony Wilkinson, Department of Archaeology, University of Edinburgh, 12 Infirmary Street, Edinburgh EH1 1LT, UK.
e-mail Tony.Wilkinson@ed.ac.uk